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RESEARCH AND EDUCATION

Translucency of IPS e.max and cubic zirconia monolithic crowns

Paolo Baldissara, DDS,[a] Vinícius Felipe Wandscher, DDS, PhD,[b] Ana Maria Estivalete Marchionatti, DDS,[c] Candida Parisi, DDS, MSc, PhD,[d] Carlo Monaco, DDS, PhD,[e] and Leonardo Ciocca, DDS, PhD[f]

ABSTRACT

Statement of problem. Although several monolithic zirconia ceramics have recently been introduced, the need for improved optical properties remains. The newest cubic-zirconia has been claimed to have optimal translucency characteristics for esthetic restorations.

Purpose. This in vitro study evaluated the optical properties of novel cubic ultratranslucent (UT) and supertranslucent (ST) zirconia by comparing them with lithium disilicate (L-DIS) glass-ceramic for the manufacture of monolithic computer-aided design and computer-aided manufacturing (CAD-CAM) molar crowns.

Material and methods. The UT and ST multilayered zirconia and the low-translucency grade L-DIS were milled. Eighty monolithic crowns were made from 2 CAD files, corresponding to thicknesses of 1.0 and 1.5 mm, and subdivided (n=20) into 4 groups: UT1.0, UT1.5, ST1.0, and L-DIS1.5. All groups were shaded using A2 color standard. Translucency of the crowns was measured by total transmission, using a photoradiometer in a dark chamber; furthermore, the contrast ratio was analyzed using a dental spectrophotometer applied to the buccal surface of the crowns. Data were analyzed using the Kruskal-Wallis and post hoc multiple Mann-Whitney *U* tests with Bonferroni correction (α=.05 divided by the number of tests performed in each set).

Results. When the ceramic types were analyzed, using total transmission and contrast methods, they showed significantly different translucency levels: UT1.0>ST1.0>UT1.5>L-DIS1.5 (total transmission $P<.001$). Contrast ratio evaluation yielded similar results ($P\leq.006$); however, the differences between ST1.0 and UT1.5 were not significant.

Conclusions. Both the ST1.0 and UT1.0 crowns, even at the maximum thickness tested (UT1.5), showed significantly higher translucency than L-DIS. Zirconia translucency was improved by eliminating the tetragonal phase, which is responsible for the toughening effect; thus, further studies are advocated to investigate the mechanical resistance of cubic zirconia. (J Prosthet Dent 2017;■:■-■)

The increased demand for improved esthetics has led to the use of ceramic systems as alternatives to metal-ceramic restorations.[1-4] To obtain optimum esthetic results, restoration optical properties must match those of natural teeth.[4-8] A key factor is translucency[2,6,9-15]: a translucent material allows the fraction of light that is not reflected to penetrate its surface where it is mainly scattered and transmitted. In particular, subsurface light scattering[16] is important for mimicking the natural appearance of hard dental tissues. If most of the light is absorbed and diffusely reflected, the material will appear opaque,[17,18] but if the light is scattered within the

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[a] Assistant Professor, Dental Materials Course, Department of Biomedical and Neuromotor Sciences, Unit of Odontostomatological Sciences, Division of Prosthodontics, Alma Mater Studiorum, University of Bologna, Bologna, Italy.

[b] Assistant Professor, Division of Prosthodontics, Federal University of Santa Maria, Rio Grande do Sul, Brazil.

[c] Assistant Professor and doctoral student, Prosthodontics Unit, Franciscan University Center, Santa Maria, Rio Grande do Sul, Brazil.

[d] Tutor, Department of Biomedical and Neuromotor Sciences, School of Dentistry, Unit of Odontostomatological Sciences, Division of Prosthodontics, Alma Mater Studiorum, University of Bologna, Bologna, Italy.

[e] Assistant Professor, Department of Biomedical and Neuromotor Sciences, Unit of Odontostomatological Sciences, Division of Prosthodontics, Alma Mater Studiorum, University of Bologna, Bologna, Italy.

[f] Researcher, Department of Biomedical and Neuromotor Sciences, School of Dentistry, Unit of Odontostomatological Sciences, Division of Prosthodontics, Alma Mater Studiorum, University of Bologna, Bologna, Italy.

Clinical Implications

Cubic zirconia can be used in clinical practice to produce highly esthetic anatomic contour posterior crowns.

object and most of it is diffusely transmitted, it will appear translucent.[16,18]

Among the dental ceramics, yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) has the highest mechanical properties, including relatively high toughness generated by the stress-induced tetragonal-monoclinic phase transition.[19,20] Clinical evaluations have shown promising results for zirconia as a core material for long-span fixed dental prostheses and crowns.[1,3]

However, conventional polycrystalline zirconia lack the optical properties and the subsurface reflection of light of lithium disilicate (L-DIS) and other glass-ceramic materials, appearing dull-white in color and unpleasantly opaque.[1,2] Zirconia opacity is caused by factors that generate surface scattering and refraction rather than transmittance of light.[18,21-25] Dispersed grains of larger size (±0.4 μm) than the wavelength of the incident light, the birefringence of the tetragonal grains, and the presence of defects, impurities, and segregation of alumina at the grain boundaries represent the most common causes of zirconia opacity.[18,19,26] Alumina is added to Y-TZP at approximately 0.5 wt% to 1 wt% to reduce the detrimental low-temperature degradation phenomenon.[27,28]

A previous study reported that several zirconia copings showed significantly lower translucency than the L-DIS used as a control.[2] To provide enough space for the veneering ceramic to compensate for the zirconia opacity, substantial tooth reduction is needed.[19] In addition, the most frequent clinical complication of zirconia restorations is cohesive chipping of the ceramic veneer.[1,3,24,29] Actually, zirconia veneering ceramics necessarily contain lower quantities of reinforcing, high coefficient of thermal expansion fillers,[30] making them less than the ones applied to metal-ceramic restorations.[30] Furthermore, residual tensile stresses caused by rapid cooling to room temperature at the end of the sintering phases may also enhance their propensity to fracture.[30,31]

An alternative for preventing chipping is the use of monolithic restorations without a veneering ceramic.[20,32-35] The major clinical advantage of monolithic construction is a lower ceramic thickness and consequent saving of dental tissue in comparison with veneered crowns.[32,36] In addition, monolithic zirconia showed higher fracture resistance than layered and monolithic L-DIS restorations, as well as lower cost.[37]

Table 1. Materials evaluated for translucency

Group (n=20)	Material	Manufacturer	Thickness (mm)
UT 1.0	1-mm thick Katana zirconia ultra translucent multi-layered EA2 Lot DMRFR	Kuraray Noritake	1.0
UT 1.5	1.5-mm thick Katana zirconia ultra translucent multi-layered EA2 Lot DLVUQ	Kuraray Noritake	1.5
ST 1.0	1-mm thick Katana zirconia super translucent multi-layered A2 Lot DOQCQ	Kuraray Noritake	1.0
L-DIS 1.5	1.5-mm thick IPS e.max CAD LT A2 Lot P87644	Ivoclar Vivadent AG	1.5

The authors are aware of only 1 study of the optical properties of cubic translucent zirconia using L-DIS e.max CAD low translucency (LT) grade as a control.[36] Therefore, the purpose of the present study was to assess the translucency of computer-aided design and computer-aided manufacturing (CAD-CAM) anatomic contour molar crowns composed of the new cubic zirconia ceramics by comparing them with L-DIS of LT grade. The null hypothesis was that no difference would be found in the translucency of the crowns in terms of total transmission (Tt) and contrast ratio (CR) values (α=.05).

MATERIAL AND METHODS

A mandibular right first molar was scanned with an intraoral scanner (Lava Chairside Oral Scanner; 3M ESPE) to obtain a standard tessellation language (STL) file of the tooth. Using CAD software (Dental System; 3Shape), the virtual tooth crown was digitally reduced, first by decreasing the height of the cusp tips and central fossae by 1.0 mm and then by extending the reduction to the axial walls. Once the 1.0-mm STL file was obtained, further reduction by 0.5 mm created the second 1.5-mm file; thus, the 2 preparations shared the same overall geometry. Both of the STL preparation files were imported into the CAD software, and 2 crowns, nominally 1.0 mm and 1.5 mm thick, were designed by superimposing the original anatomy of the tooth as it was before the digital reduction.

Eighty crowns were machined and subdivided into 4 groups (n=20) according to the material used and its thickness (Table 1). The sample size was determined by preliminary trials that showed closer means among the groups and higher standard deviations (SD) for the CR analysis method rather than for Tt method. Thus, the hypothesis was based on the CR evaluation with a mean ±SD difference between the groups of 0.03 ±0.025 and a power of 80% with α=.05; the given sample size was 19 units per group.

Ultratranslucent 1.0-mm and 1.5-mm thick (UT 1.0 and UT 1.5, respectively) and supertranslucent

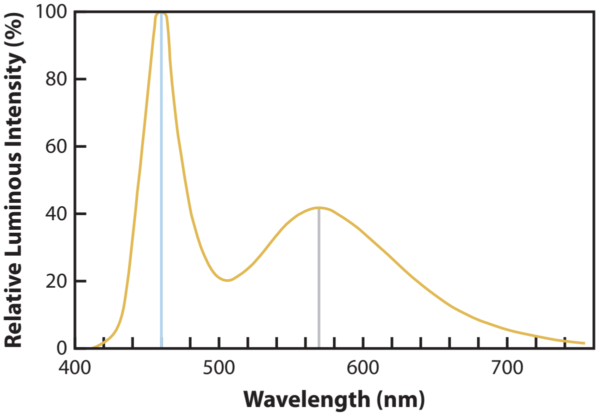

Figure 1. Representative light emission curve of LED source and relative luminous intensity. Note peaks of relative intensity at 460 (100% [blue-violet]) and 565 nm (40% [green]). LED, light-emitting diode.

Figure 2. Cubic zirconia UT 1.5-mm crowns placed on black and white dies used as backgrounds in CR measurements. Note great color differences generated by dark background, giving measurements of material's high translucency. Panavia V5 clinical evaluation paste served as optical connection between dies and crowns. CR, contrast ratio; UT 1.5, Katana zirconia ultra translucent multi-layered EA2 Lot DLVUQ.

1.0-mm thick (ST 1.0) cubic zirconia blanks (Katana STML and UTML; Kuraray Noritake Dental Inc) were milled (Mikron HSM 400U LP machine; Agie-Charmilles GF). L-DIS 1.5-mm thick (L-DIS 1.5) IPS e.max CAD LT (Ivoclar Vivadent AG) was machined using a CEREC inLab MC XL (Dentsply Sirona). The thickness of the crowns was selected according to the manufacturer's indications for posterior crowns, that is, 1 mm for the Katana ST and UT zirconia crowns and 1.5 mm for the L-DIS IPS e.max CAD LT crowns. Katana UT 1.5 zirconia crowns were also made for comparison. After the zirconia crowns were milled, they were sintered according to the manufacturer's recommendation in an authorized milling center facility without further glazing. Crystallization and glaze firing of the milled L-DIS crowns were achieved at the same time by a Dentsply Sirona-licensed dental technician, whereas zirconia crowns were manually polished using rubber diamond points (Edenta AG), ST102 HP, followed by Star Gloss R1020HP, and then R1040HP. Once received, the crowns were evaluated with mechanical calipers accurate to within 0.1 mm (Iwansons caliper; ASA Dental) to ensure uniform thickness in each test group.

Translucency was evaluated by using the Tt and CR methods. The order of measurements in each of the 2 evaluation methods was determined by using random number generator software. Groups were labeled 1 to 4, and a series of 80 numbers with an equal chance of choosing any integer between 1 and 4 was created. The crowns were tested following the column order, which was used for both the Tt and the CR analyses.

To determine the Tt (or illuminance), a light beam generated by 2 light-emitting diode (LED) sources (InGaN white LED; The LED Light Inc) with emission at 410 to 760 nm and peak intensity at 455 and 565 nm of 100% and 40% (Fig. 1) was passed through the crowns in a dark chamber. The position and orientation of each crown in the receptacle of the light duct were standardized. The sensor of a digital photoradiometer (HD 9221/S3; Delta Ohm Srl) with a spectrum range of 400 to 800 nm was positioned in the dark chamber to detect the quantity of light directly and diffusely transmitted exiting the internal surface of the crowns. The light duct extending to the dark chamber was 25% smaller (8.7-mm inside diameter) than that of the crown receptacle to prevent direct light passing beyond the axial profile of the crown. The system was sealed so that no external light other than the radiation passing through the ceramic crown could reach the sensor. Measurements were expressed as illuminance units (lx) to describe the quantity of direct and diffused light per unit area arriving at the sensor surface in a certain time. To determine the repeatability and reproducibility of the measurement system, a crown was placed in the chamber receptacle and measured and repositioned 20 times; the intraclass correlation coefficients were 0.9 and 1. The measurements were repeated 3 times, and the means were calculated. The dark chamber was tested by using the LED off and with the maximum uninterrupted light flow before each measurement session, checking for both 0 and a constant light flow value. Fluctuations of up to 0.01 lx at 0 light were considered the instrument uncertainty.

The CR analysis was performed using a spectrophotometer (Spectroshade; MHT Optic Research AG) to measure the reflectance of the ceramic specimens placed on white and black backgrounds: 4 resin dies,

Table 2. Mean ±SD light flow values (lx ×10^3), and medians obtained by Tt test and expressed as translucency percentages relative to most translucent group (UT 1.0)

Group	Mean ±SD*	Median	Translucency Related to UT 1.0 group (%)
UT 1.0	75.0 ±0.5^A	74.8	100
ST 1.0	68.4 ±0.5^B	68.5	91.2
UT 1.5	65.2 ±1.6^C	65.3	87
L-DIS 1.5	35.2 ±0.9^D	35.1	47

UT 1.0, 1-mm thick Katana zirconia ultra translucent multi-layered EA2 Lot DMRFR; UT 1.5, 1.5-mm thick Katana zirconia ultra translucent multi-layered EA2 Lot DLVUQ; ST 1.0, 1-mm thick Katana zirconia super translucent multi-layered A2 Lot DOQCQ; L-DIS 1.5, 1.5-mm thick IPS e.max CAD LT A2 Lot P87644. *Different superscript uppercase letters indicate statistical differences. Kruskal-Wallis test, $P<.001$.

Table 3. Mean ±SD and medians obtained with CR analysis[a]

Group	Mean ±SD[b]	Median
UT 1.0	0.76 ±0.04^A	0.78
ST 1.0	0.79 ±0.03^B	0.80
UT 1.5	0.81 ±0.03^{A,C}	0.81
L-DIS 1.5	0.84 ±0.02^C	0.84

UT 1.0, 1-mm thick Katana zirconia ultra translucent multi-layered EA2 Lot DMRFR; UT 1.5, 1.5-mm thick Katana zirconia ultra translucent multi-layered EA2 Lot DLVUQ; ST 1.0, 1-mm thick Katana zirconia super translucent multi-layered A2 Lot DOQCQ; L-DIS 1.5, 1.5-mm thick IPS e.max CAD LT A2 Lot P87644. [a]Value 0=most translucent; value; 1=most opaque. [b]Different superscript uppercase letters indicate statistical differences. Kruskal-Wallis test, $P\leq.006$.

2 for each crown thickness, were milled using the corresponding STL files originally used to design the crowns. The dies were painted with black (RAL 9005) or white (RAL 9010) acrylic spray varnish. Panavia V5 clinical evaluation paste A2 (Kuraray Noritake Dental Inc) was used to create an optical connection with the dies, simulating the cement effect (Fig. 2). The data were obtained by alternatively placing the crowns on the white and black dies, making 3 readings of the buccal surface in each condition. The same operator (V.F.W.) calibrated the spectrophotometer every 20 measurements. The means and SD were calculated using the following formula[17,18]: $CR=Y_b/Y_w$, where $Y=[(L+16)/116]^3\times 100$. Y_b and Y_w refer to the light (L) reflectance values of the specimen over the black and white backgrounds. A value of 0 means the specimen is transparent (0 opacity), whereas 1 indicates total opacity.

The normality of distribution and homogeneity of variance (homoscedasticity) of the data were assessed by the Shapiro-Wilk and Levene tests. Because the parametric assumption was not satisfied ($P<.05$), the Kruskal-Wallis test followed by the post hoc multiple Mann-Whitney *U* tests were performed with Bonferroni correction to compare the groups in terms of both the Tt and CR methods. A significance level of $\alpha=.05$ divided by the number of tests performed in each set was adopted.

RESULTS

Both the Tt and CR methods differed significantly between groups. Tt values decreased in the following order: UT 1.0 > ST 1.0 > UT 1.5 > L-DIS 1.5; all differences between groups were significant ($P<.001$). When analyzed using CR, the lowest value (highest translucency) was found for the UT 1.0 group, whereas L-DIS 1.5 showed the highest CR ($P\leq.006$). No statistically significant differences were observed between the ST 1.0 and UT 1.5 groups ($P=.099$).

The Tt and CR values are summarized in Tables 2 and 3. The Tt data are also expressed as translucency percentages relative to the most translucent group (UT 1.0).

DISCUSSION

Because the crowns had different levels of translucency when measured using the Tt method ($P<.001$), the null hypothesis was rejected. Using CR analysis, the null hypothesis was partially rejected as only the ST 1.0 and UT 1.5 groups were not significantly different ($P=.099$).

No consensus has been reached in dental studies about the different methods adopted to quantify translucency.[6] Calculation of the translucency parameter is one of the most common approaches to evaluating light interactions in a dental restorative material. Translucency parameter has the advantage of direct visual assessment of translucency but cannot be used to evaluate dental crowns because of the complex and curved surfaces of the restorations; thus, Tt and CR were used in this study.

Tt represents the transmitted light emerging from the crowns that reaches the photoradiometer, with the crown body acting as an interposed screen. Tt also includes direct transmission, which is the unaffected, straight light penetrating the translucent specimen from one side to the other. In this study, the white light beam was directed perpendicularly to the occlusal surface, and after being reflected by the complex morphology of the crown surface and scattered/absorbed within the ceramic bulk, it emerged from the intaglio surface to reach the sensor.

The CR parameter has been widely reported.[5,8,14,17,18] Unlike Tt, in this study, the CR evaluation was carried out on the buccal surface of the crowns. The morphology of the buccal surface, although convex, is simpler than that of the occlusal surface, so the value, or reflectance variations when passing from a white to a black background, can be detected by the Spectroshade instrument and transformed into a translucency value. Even if the different chroma levels of the multilayer zirconia crowns blurred the CR data, the Tt analysis still confirmed the CR results. Furthermore, the perception threshold perceptible to the human eye is a CR difference ranging from 0.06 to 0.07[5]; in the present study, the mean CRs for UT 1.0 and L-DIS 1.5 were 0.76 and 0.84, respectively, a

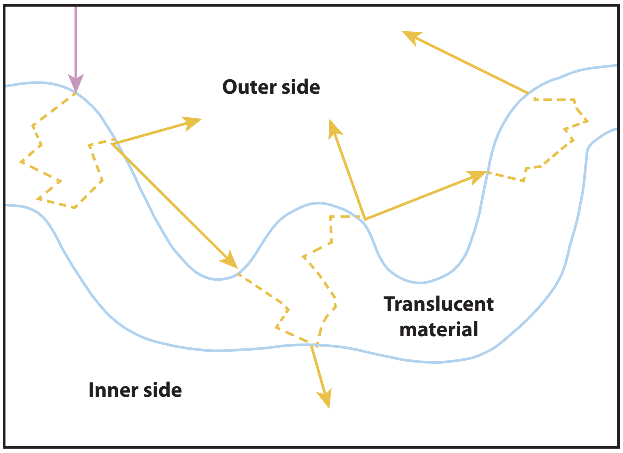

Figure 3. Schematic of light paths in translucent object with uneven surface that could be approximated by that of ceramic crown. Violet arrow represents incident light rays diffused beneath surface as subsurface scattering (orange dotted lines). Light can emerge and/or re-enter surface at different points (orange arrows). Interreflection phenomena occur in free space within surface curvatures and, together with subsurface scattering, generate natural tooth-like appearance. Adapted from Sheng et al.[16]

difference of 0.08 (Table 3). According to these data, such a dissimilarity between ceramics might be clinically detectable.

The translucency (Tt) of ST 1.0 was significantly higher than that of UT 1.5. Although UT is more translucent than ST, the translucency decreases as ceramic thickness increases,[4,22] which explains the lower Tt value in the UT 1.5 group. The minimal thickness recommended by the manufacturers is 1.5 mm for L-DIS and 1.0 mm for Katana UT and ST; UT 1.5 was included in the present study for comparison with L-DIS 1.5. Both the UT 1.0 and UT 1.5 showed greater translucency than L-DIS. Besides the advantage of a more conservative preparation, a thinner and more translucent crown allows a greater amount of light transmission through the ceramic and an increased conversion degree during cementation with resin-based materials, positively affecting polymerization.[18,22] Therefore, a ceramic that for the same degree of translucency requires the minimum restoration thickness should be selected.

LT and high-translucency grade L-DIS are more translucent than BruxZir (Glidewell Laboratories) and Metoxit (High Tech Ceramics) zirconia for monolithic restorations.[11,23] These high-translucency ceramics (Y-TZP) belong to the previous generation of optically improved zirconia, and the results are not in accordance with those of the current study, in which the newest cubic phase Katana ST and UT were used.

The manufacturer claims for ST and UT are a cubic grain percentage of 100%, stabilized with 5.0%mol and 5.5%mol yttria. Unlike the tetragonal grains, which are optically anisotropic, the cubic grains have an isotropic refractive index, reducing the high scattering at the grain boundaries, typical of Y-TZP ceramics. The ceramic translucency is consistently improved when most of tetragonal grains are replaced by isotropic cubic grains.[19,20,25] A further increase in translucency is due to the reduced content of alumina and porosities. A recent study[36] reported that, in Katana ST and UT zirconia, the alumina concentration was reduced to 0.26 wt% and 0.11wt%, respectively. Residual porosity at the grain boundary, even at small sizes and quantities, has a detrimental effect on the translucency of zirconia by increasing the refractive index and light scattering.[19,20] One method of closing pores and increasing the density of the material is to use higher sintering temperatures, in the range 1510°C to 1550°C.[17,19] The zirconia-sintering program used in the present study involved a sintering temperature of 1550°C, which may be associated with, among other variables, high translucency.

The results obtained here indicated that cubic zirconia is more translucent than L-DIS 1.5, with Katana UT 1.0 the most translucent ceramic, agreeing in part with the findings of Harada et al,[36] who evaluated the percentage of light transmitted through Katana UT and ST 0.5-mm-thick flat specimens. They found that UT was significantly more translucent than ST, although the 2 ceramics showed similar transmittance when the specimen thickness was increased to 1 mm. The current study confirmed the translucency of Katana UT was higher than that of ST but also showed that, at the same thickness of 1.5 mm, UT zirconia was significantly more translucent than LT L-DIS. The translucency of the ST 1.0 group was 91.2% of that of the UT 1.0 group, whereas the translucency of L-DIS 1.5 was approximately half that of ST 1.0. Indeed, UT 1.5, which had the same thickness as L-DIS 1.5, showed a significantly higher value than that of the glass-ceramic. Such a difference in translucency between UT and L-DIS was unexpected.

Even though both studies evaluated the same brand and translucency grade (LT) of L-DIS, the color was different (A2 versus B1, respectively). A2 shade contains more chroma than B1, so the greater pigment content of A2 crowns used in the present study could have absorbed more light[35] than that recorded for B1 specimens, potentially explaining the superior translucency of L-DIS. However, even if the Katana UT and ST zirconia specimens analyzed by Harada et al[36] were not colored, their light transmission values were still surprisingly lower than those of B1-shaded LT L-DIS.

Other factors could explain the different results of the 2 studies. The present study compared ceramics in the form of a mandibular molar crown. This approach, rarely used in the dental reports, allows the evaluation of the optical behavior of an actual prosthesis, rather than that of a flat specimen. Multiple and intricate light paths in and out of the ceramic bulk are only possible on curved and textured surfaces such as those of crowns (Fig. 3). The complex pathways created by light striking a translucent, anatomically shaped ceramic are mainly responsible for the lifelike appearance.[16] Therefore, this study evaluated the light transmission along with the anatomic variables of a ceramic restoration. Optical effects related to surface shapes are not considered in studies that use flat disks or tablet-shaped specimens; therefore, the translucency data obtained here might more closely resemble clinical observations. However, determining to what extent shape variables influence the optical behavior of a translucent, refractive ceramic is not possible.

Another explanation of the contrasting results could be the type of light used for the translucency analysis. As light transmittance percentages in dental ceramics differ according to the wavelengths passing through the material,[26] different wavelengths may give different estimations of the ceramic translucency. To compare the ceramics specimens, Harada et al[36] used a wavelength of 555 nm (green light), because this is the radiation to which the human eye is most sensitive.[18,32]

Instead, in the present study, a white light beam with a 460-nm maximum peak of relative luminous intensity was used to assess the Tt values of the ceramics (Fig. 1). This predominant radiation corresponds to a blue-violet light, relegating the green radiation to a second 565-nm peak of only 40% intensity. Thus, the predominance of blue-violet wavelengths within the white light beam may contribute to the superior translucency of UT and ST cubic zirconia. The observation in the study by Harada et al[36] that the transmittance values shown by UT and ST 1.0 mm specimens at lower wavelengths are better than those of e.max CAD LT L-DIS corroborates this last hypothesis.

As the results were partially in contrast with recent findings, further studies are necessary. The reduction or complete absence of tetragonal grains in the newest cubic zirconia suggests that further investigations of their mechanical properties are required to better characterize their clinical application.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Tt evaluation showed that both Katana ST and UT cubic zirconia crowns are more translucent than L-DIS crowns (LT) when a white light beam with predominantly blue-violet wavelengths is used ($P<.001$),
2. CR analysis closely confirms the Tt results ($P\leq.006$),
3. Owing to their higher translucency, cubic zirconia ceramic appears to be a promising material for highly esthetic, anatomic contour restorations.

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Corresponding author:
Prof Paolo Baldissara
Department of Biomedical and Neuromotor Sciences (DIBINEM)
Alma Mater Studiorum, University of Bologna
Division of Prosthodontics
Via San Vitale 59 – 40125 Bologna
ITALY
Email: paolo.baldissara@unibo.it

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